B_s Mixing
&
B_s Lifetime Difference
@ D∅

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PANIC 2005
Tuesday, October 25, 2005

The Unitarity Triangle

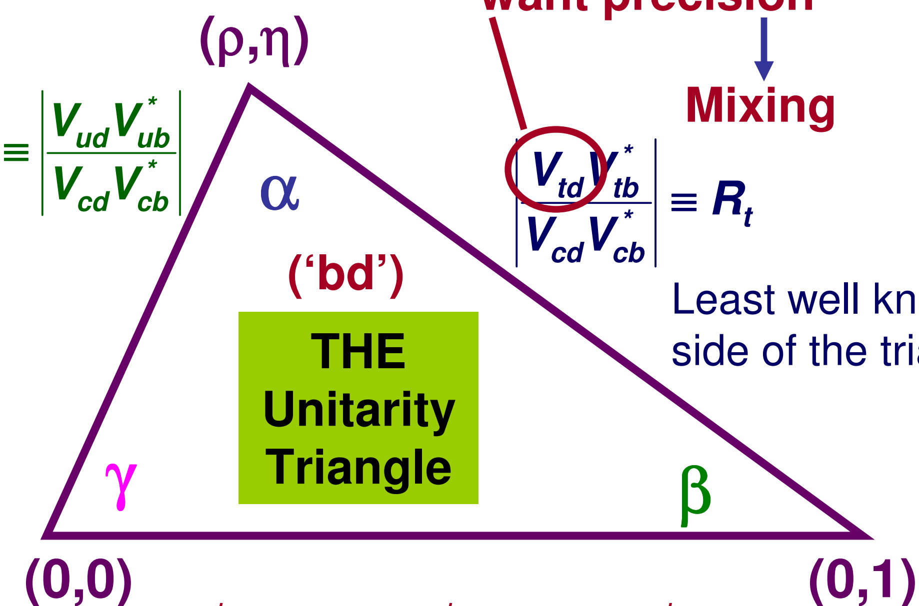
$$V_{CKM} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

Constraining the CKM matrix redundantly using different measurements of the angles/sides is a sensitive probe of New Physics

want precision

Mixing

$$R_u \equiv \left|\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right|$$



$$\left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right| \equiv R_t$$

Least well known side of the triangle

$$V_{ub}V_{ud}^* + V_{cb}V_{cd}^* + V_{tb}V_{td}^* = 0$$

Area of the triangle indicates CP violation in the SM due to the CKM matrix

'bs'
(Squashed unitarity triangle)

$\beta \rightarrow \beta_s$

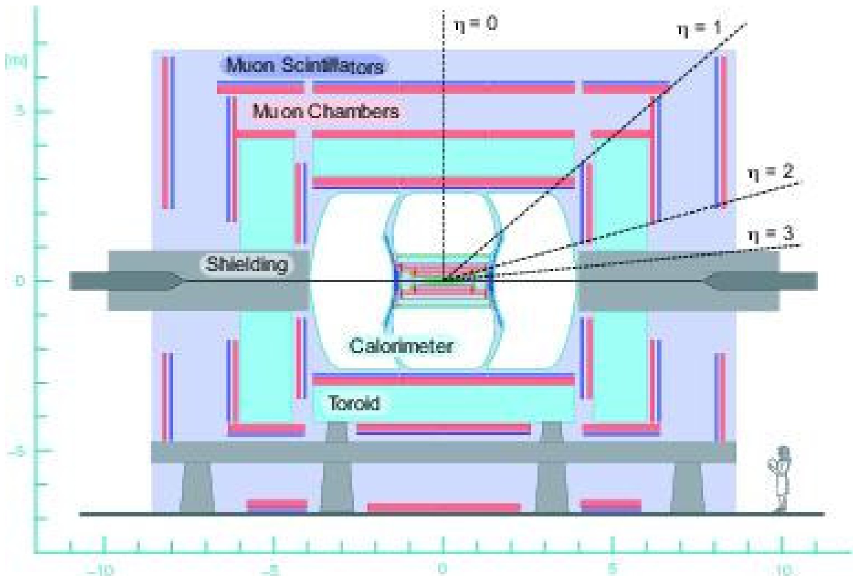
SM: β_s small

$\Rightarrow$ CP violation is small

Checking this is complementary to measuring the sides/angles of THE Unitarity Triangle

(currently only at the Tevatron)

B Physics @ DØ



$$\sigma(p\bar{p} \to b\bar{b}) \approx 150\mu b \text{ @1.96 TeV}$$
$$\sigma(e^+e^- \to b\bar{b}) \approx 7nb \text{ @ } Z^0$$
$$\sigma(e^+e^- \to B\bar{B}) \approx 1nb \text{ @ } \Upsilon(4S)$$

Large production cross-section
All B species, including **B_s**, B_c, Λ_b

Rich B Physics program at DØ benefits from :

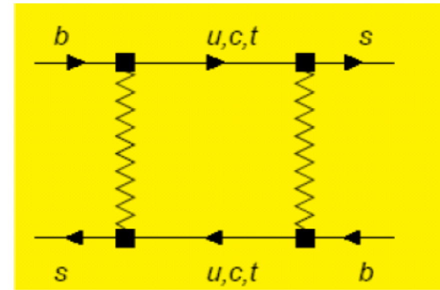
- Large muon acceptance: $|\eta| < 2$
- Forward tracking coverage:
  $|\eta| < 2.0$ (tracking), $|\eta| < 3$ (Si)
- Robust muon trigger

B_s Mixing: 610 pb^{-1}

B_s Lifetime difference: 450 pb^{-1}

Mixing Phenomenology

$$\hat{H}\begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix} = \begin{pmatrix} M - \frac{i\Gamma}{2} & M_{12} - \frac{i\Gamma_{12}}{2} \\ M_{12}^* - \frac{i\Gamma_{12}^*}{2} & M - \frac{i\Gamma}{2} \end{pmatrix} \begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix}$$



M_{12} : from real part of box diagram, dominated by **top** quark

Γ_{12} : from imaginary part of box diagram, dominated by **charm**

Two physical states (heavy and light B_s) propagate with distinct masses and lifetimes

$$B_L = p|B_s\rangle + q|\bar{B}_s\rangle \approx \text{cp even} \qquad B_H = p|B_s\rangle - q|\bar{B}_s\rangle \approx \text{cp odd}$$

$$\Delta m = M_H - M_L \approx 2|M_{12}| \qquad \Delta\Gamma = \Gamma_L - \Gamma_H \approx 2|\Gamma_{12}|\cos\phi$$

CP violating phase $\phi = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right)$ **~ - 0.03 (SM) $\Rightarrow$ mass eigenstates $\approx$ CP eigenstates**

Δm_d has been precisely measured: **0.509 ± 0.004 ps^{-1}**

$$\Delta m_d = \frac{G_F^2 m_W^2 \eta S(m_t^2/m_W^2)}{6\pi^2} m_{B_d} f_{B_d}^2 B_{B_d} |V_{td}^* V_{tb}|^2$$

$f^2_{Bd}B_{Bd}$ = (228$\pm$30$\pm$10 MeV)^2

$|V_{td}|$ from Δm_d limited by ~15%

$\therefore$ consider ratio

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{Bs}}{m_{Bd}} \frac{f_{Bs}^2 B_{Bs}}{f_{Bd}^2 B_{Bd}} \frac{|V_{ts}|^2}{|V_{td}|^2} = \frac{m_{Bs}}{m_{Bd}} \xi^2 \frac{|V_{ts}|^2}{|V_{td}|^2}$$

ξ = 1.21$\pm$0.04$\pm$0.05

Many theoretical uncertainties cancel

Determine $|V_{ts}|/|V_{td}|$ ~ 5% precision

Measure $\Delta m_s \Rightarrow$ constrain V_{td}

Mixing analysis in a nutshell

K mixing $\Rightarrow$ direct & indirect CPV
B_d mixing $\Rightarrow$ heavy top mass
ν mixing $\Rightarrow$ neutrino mass $\neq 0$

B_s mixing $\Rightarrow$????

Current world limit: $\Delta m_s > 14.4\ ps^{-1}$ @95% CL

B_s oscillates > 30 times faster than B^0 !

Δm_s measurement experimentally very challenging

Analysis Strategy

- Select final states suitable for the study
- Determine proper decay time
- Obtain # of oscillated or non-oscillated events (flavor tagging)
  - Tag B meson flavor at **decay** time (final state)
  - Tag B meson flavor at **production** time (initial state)

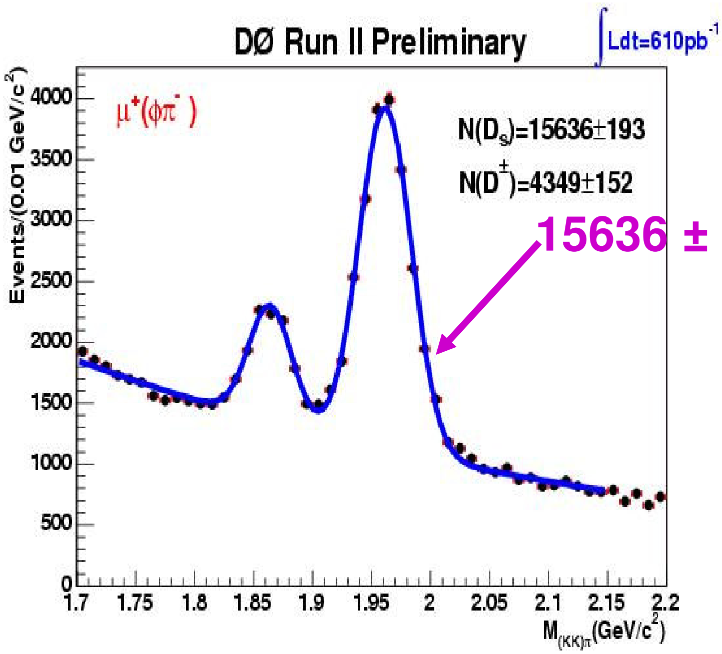
  If flavor of B at decay = flavor at production $\Rightarrow$ B hadron non-oscillated
  If flavor of B at decay $\neq$ flavor at production $\Rightarrow$ B hadron oscillated
- Fit for Δm (or amplitude at Δm_s)

$$A(t_{B_s}) = \frac{N^{non-osc}(t_{B_s}) - N^{osc}(t_{B_s})}{N^{non-osc}(t_{B_s}) + N^{osc}(t_{B_s})} \propto \cos(\Delta m_s \cdot t_{B_s})$$

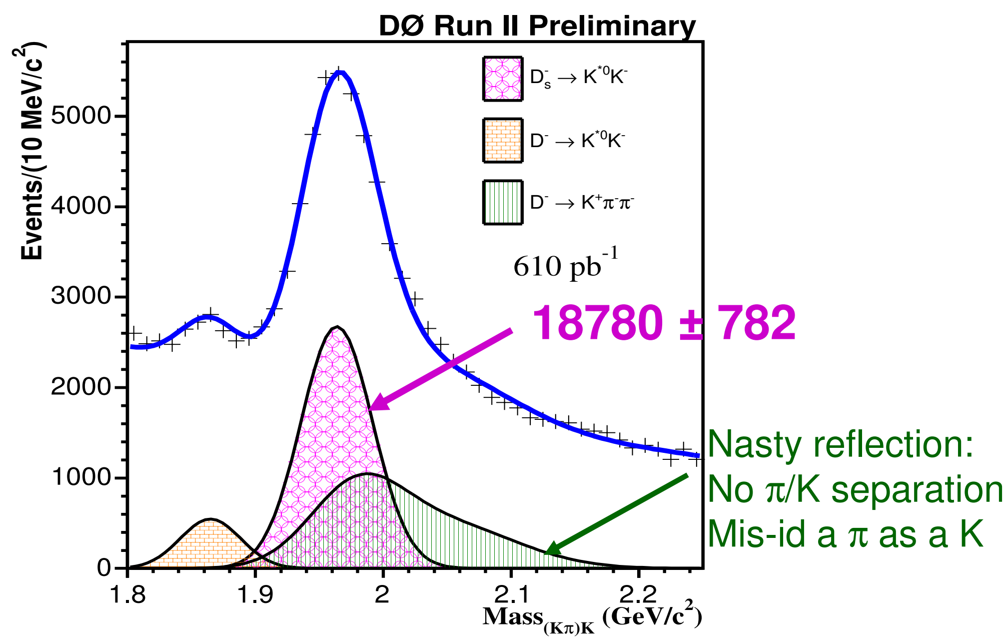
Essential ingredients

610 pb^{-1}

$B_S \to D_S\, \mu\, X$; $D_s \to \varphi\, \pi$; $\varphi \to K^+K^-$



$B_S \to D_S\, \mu\, X$; $D_s \to K^{*0}K$; $K^{*0} \to K\pi$



Determine proper time:

Inferred from B candidate's decay length (w.r.t. PV) and its momentum.

Semileptonic decays ⇒ Bs momentum can only be reconstructed partially.

decay length vector in the transverse plane

$$ct_{B_s} = x^M \cdot K \qquad K \equiv p_T^{D_s\mu} / p_T^{B_s} \qquad x^M \equiv \left(\vec{L}_{xy} \cdot \vec{p}_{xy}^{\,D_s\mu}\right) / \left(p_T^{D_s\mu}\right)^2 \cdot m_{B_s}$$

"K factor" **"visible proper decay length (VPDL)"**

VPDL resolution and K-factor distributions obtained from simulation

Flavor Tagging

- Tag B meson flavor at **decay**: use charge of final state particles: $b \rightarrow \mu^-$
- Tag B meson flavor at **production**: use opposite-side techniques
  - use decay products of the “other b” to infer the initial flavor of the reco’d B_s
    - Soft lepton tagging (SLT) : $b \rightarrow \mu^-$ or e^-
    - Muon Jet Charge, secondary vertex

- Make B_d oscillation measurement
  - use same opposite-side tagger as for B_s

D = 0.384 ± 0.014 ± 0.006

εD^2 = (1.94 ± 0.14 ± 0.09)%

$\boxed{D = 2\eta - 1}$

η: purity

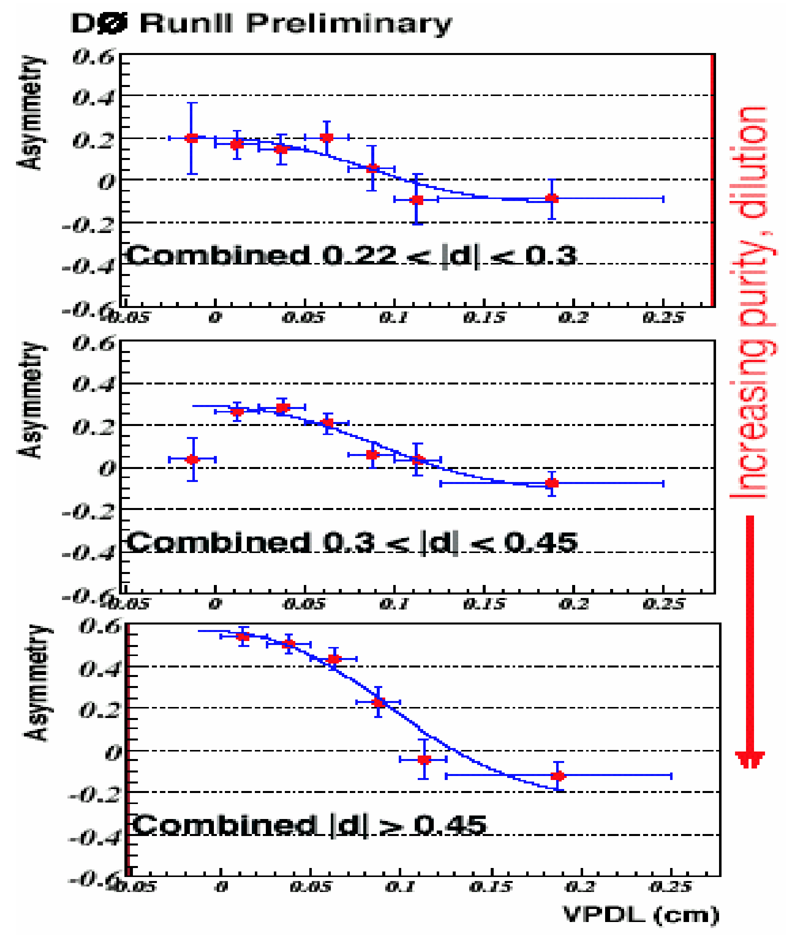
$$\Delta m_d = 0.501 \pm 0.030 \pm 0.016 \ \mathrm{ps}^{-1}$$

Consistent with the world average

610 pb^{-1} **~4.2 K tagged B_S events**

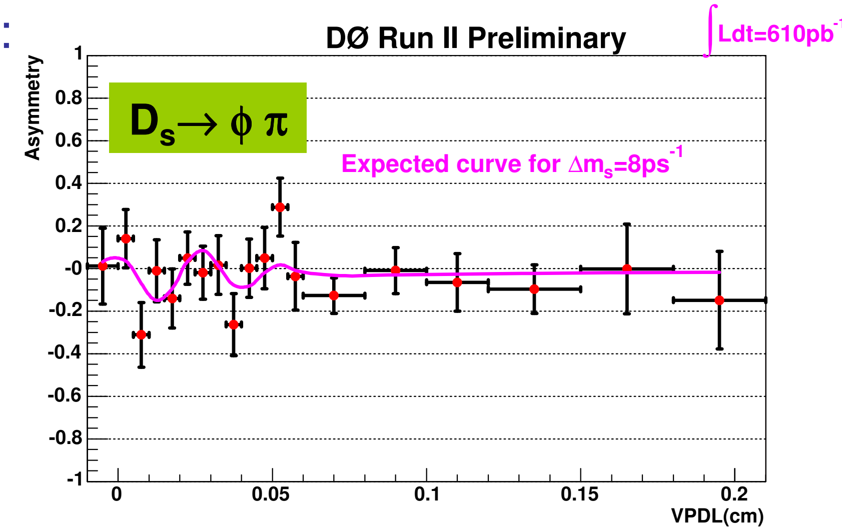
Tagging efficiency ~ 12.3%

Useful B_S signal fraction ~ 88%



Asymmetries

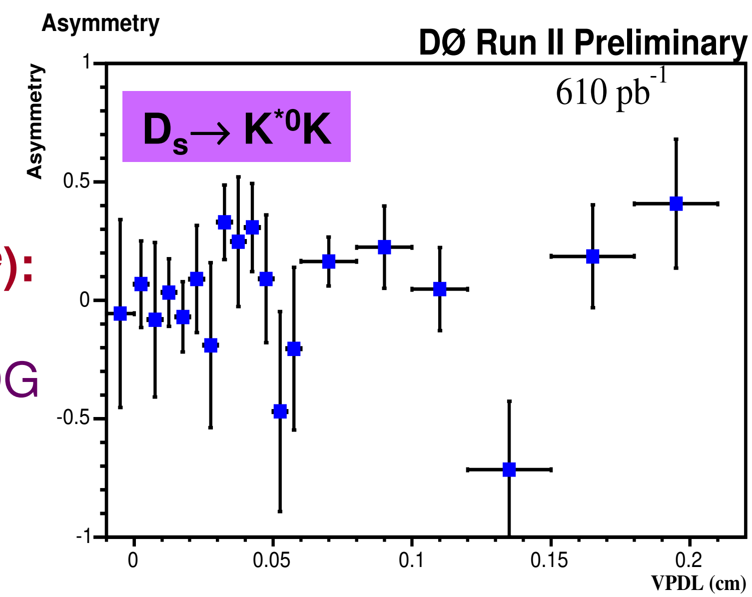
- Split B_s data sample into different bins of VPDL:



- Obtain # of events tagged as "non-oscillated" & "oscillated" for each VPDL bin by fitting D_s mass spectra:

- Calculate asymmetry for each VPDL bin **(A^{meas}):**

$$A_i^{meas} = \frac{N_i^{non-osc} - N_i^{osc}}{N_i^{non-osc} + N_i^{osc}}$$

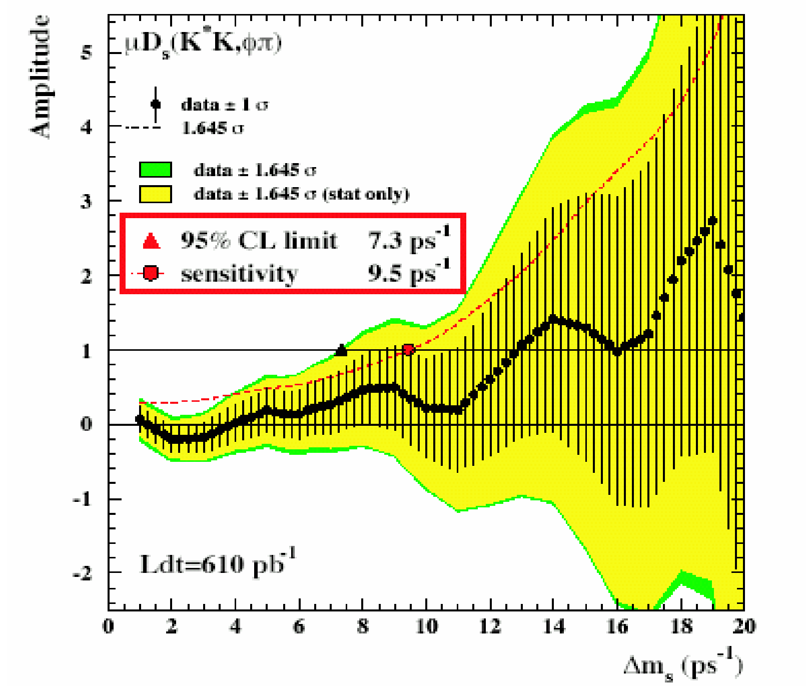


No obvious oscillations…

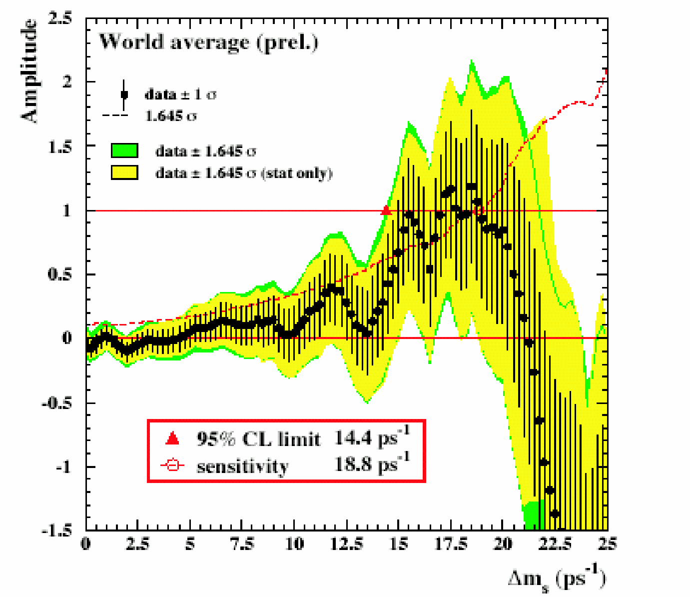
- Calculate expected asymmetry for each bin **(A^e):**

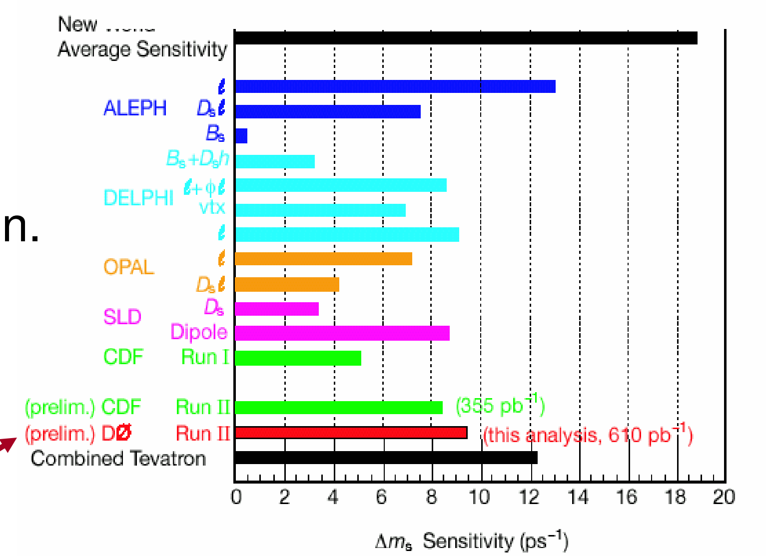
B meson lifetimes and branching rates from PDG
K-factor distributions, decay length resolution, reconstruction efficiencies from MC

Amplitude Fit Method



World Average





Dominant sources of systematic uncertainty:
understanding of VPDL resolution, K factors, Sample composition, uncertainty in tagging dilution.

Combined D∅ result:

Limit: Δm_s > 7.3 ps^{-1} @ 95% C.L.

Sensitivity: 9.5 ps^{-1} @ 95% C.L.

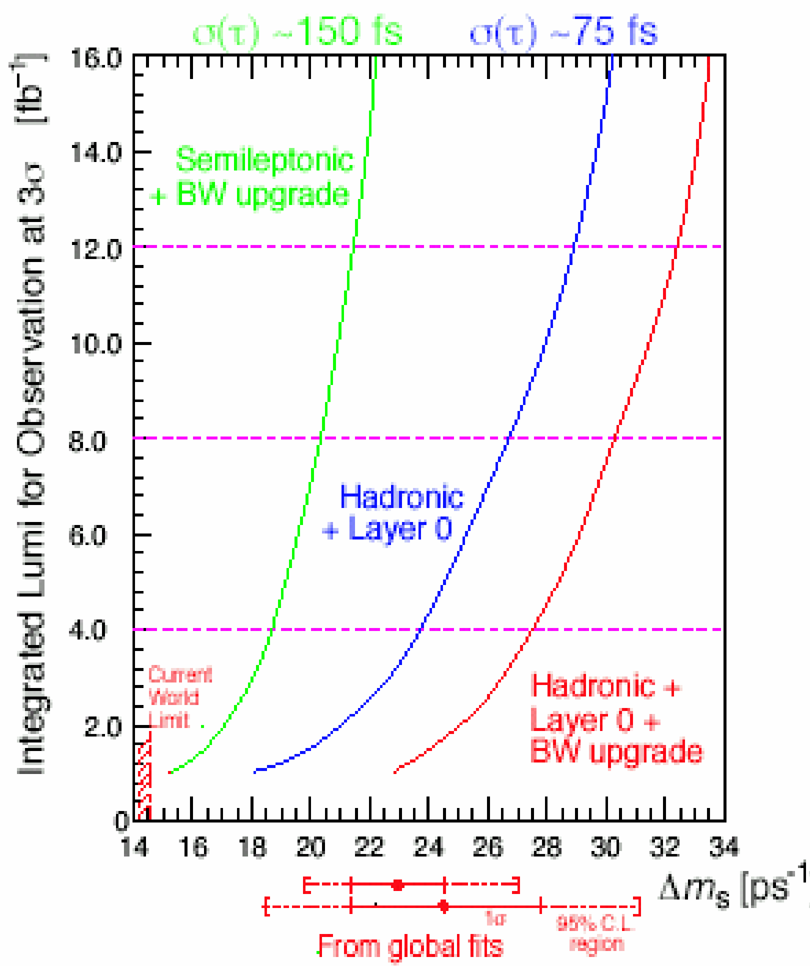
Future Improvements

Analysis techniques:
- Add more decay channels
- Improve opposite-side tagging,
- Add same-side tagging
- Unbinned likelihood fit: event-by-event resolution and tagging purity

Hadronic B_s decays:
- Trigger on flavor-tagging muon, verify yield (Excellent decay length resolution)

Bandwidth increase:
- Current limit for B triggers is rate to tape
- Bandwidth increase from 50 to 100Hz
- Proposal to process extra 50Hz of B Physics data at remote institutions

Hardware – new Layer 0 Silicon
- Radius of 1.7cm inside current detector
- Improve decay length resolution by ~30% even if lose Layer 1

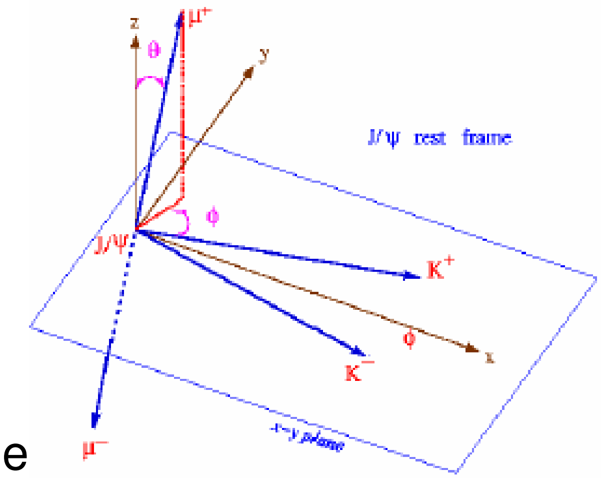


And more data!

B_s lifetime difference analysis

$B_s \rightarrow J/\psi\ (\mu^+\mu^-)\ \phi\ (K^+K^-)$
Pseudoscalar → Vector Vector

cosθ=transversity

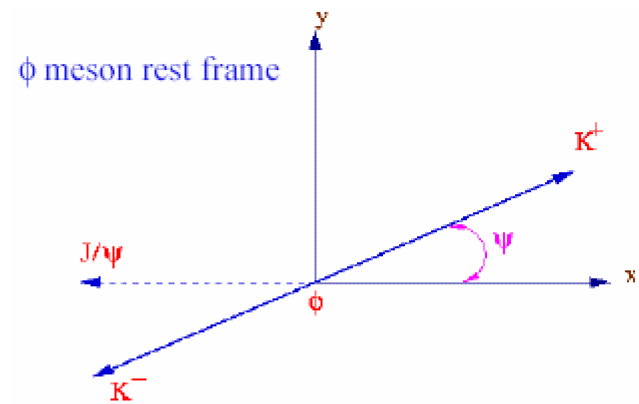


Three waves: **S, P, D** or **A_0, $A_{||}$, $A_\perp$**

S, D (Parity, CP even): linear combination of **A_0, $A_{||}$**
P (Parity, CP odd): **$A_\perp$**

Decay parameterised by three angles:

Azimuthal (φ) and polar angle (θ) wrt the direction of the μ+ in the J/ψ rest frame
Polar angle (ψ) of K^+ in φ rest frame



Both CP-even and CP-odd present but are well separated in **transversity (cosθ)**

We integrate over two angles: φ and ψ

$$\frac{d\Gamma(t)}{d\cos\theta} \propto \left(\left|A_0(t)\right|^2 + \left|A_{||}(t)\right|^2\right)\frac{3}{8}\left(1+\cos^2\theta\right) + \left|A_\perp(t)^2\right|\frac{3}{4}\sin^2\theta$$

Integral for flat efficiency in ψ, φ

Non-uniform acceptance in φ integration leads to small correction term

Analysis strategy

Measure **TWO** distinct lifetimes (or, equivalently, $\Delta\Gamma/\Gamma$ and τ)

- fit time evolution & transversity distr. in untagged B_s decays
- If CP is conserved, they can be interpreted as the lifetimes of the two B_s mass eigenstates

Simultaneous fit to mass, lifetime and transversity using an unbinned maximum likelihood method

Candidate Events

Fraction of signal

$$Likelihood = \prod_{i=1}^{N} \left[f_{sig} F^{i}_{sig} + (1 - f_{sig}) F^{i}_{bkg} \right]$$

Product of mass, proper decay length and transversity PDFs

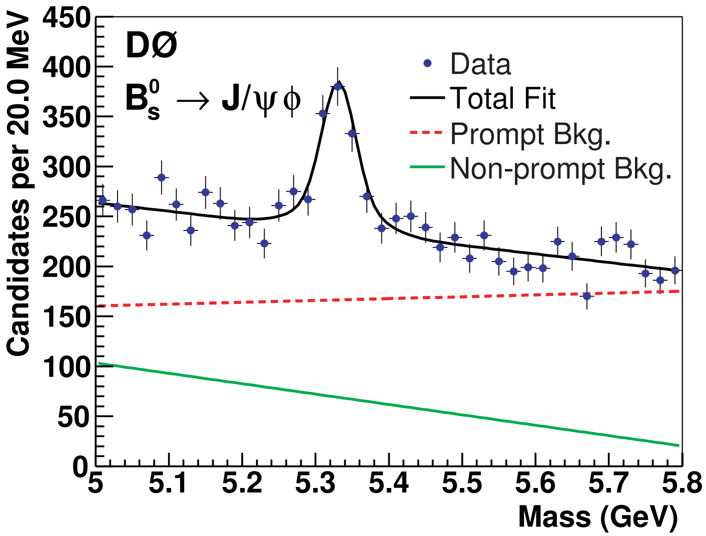
19 parameters:	1	f_{sig}	signal fraction
	2	signal mass, width	
	1	$R_\perp$	CP-odd fraction at t=0
	1	$c\tau = c/\bar{\Gamma}$,	$\bar{\Gamma} = (\Gamma_L + \Gamma_H)/2$
	1	$\Delta\Gamma / \bar{\Gamma}$	
	2	bkg slope in mass (1 prompt, 1 long-lived)	
	1	$\sigma(ct)$ scale	
	6	bkg ct shape	
	4	bkg transversity (2 prompt +2 long-lived)	

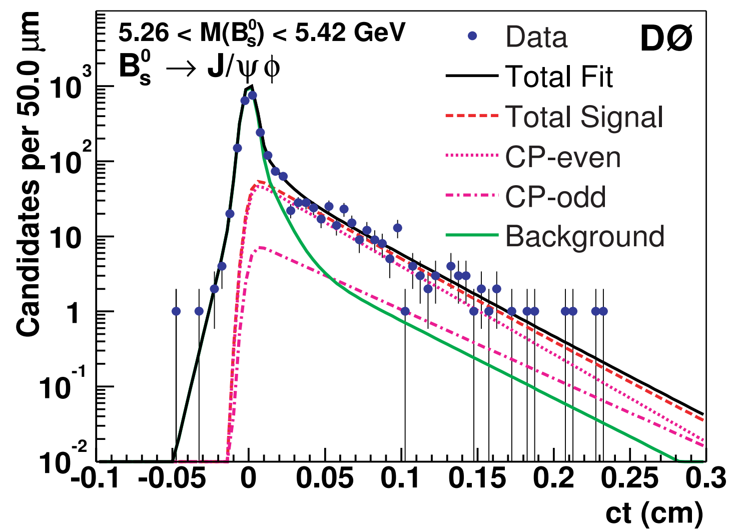
$$\bar{\Gamma} = \frac{\Gamma_H + \Gamma_L}{2}$$

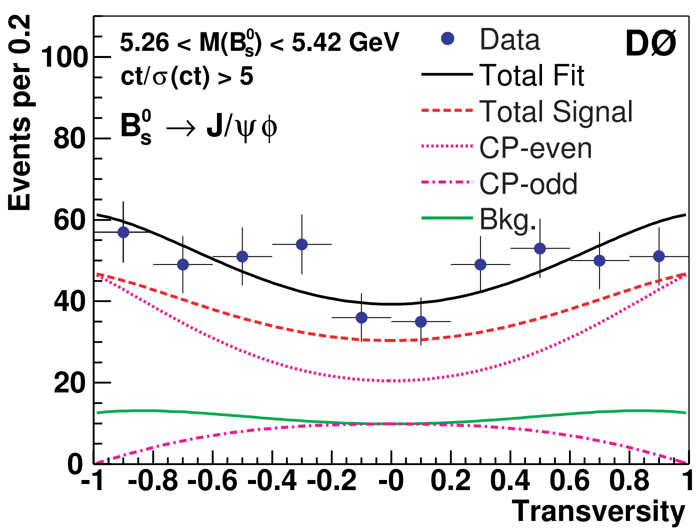
$R_\perp$: CP-odd fraction at t=0

B_s mass & Lifetime

450 pb^{-1}







Signal Fit Results

events	513 ± 33
$c\bar{\tau} = c/\bar{\Gamma}$	416^{+39}_{-48} μm
$\Delta\Gamma/\bar{\Gamma}$	$0.24^{+0.28}_{-0.38}$
$R_\perp$	0.16 ± 0.10

Semileptonic constraints

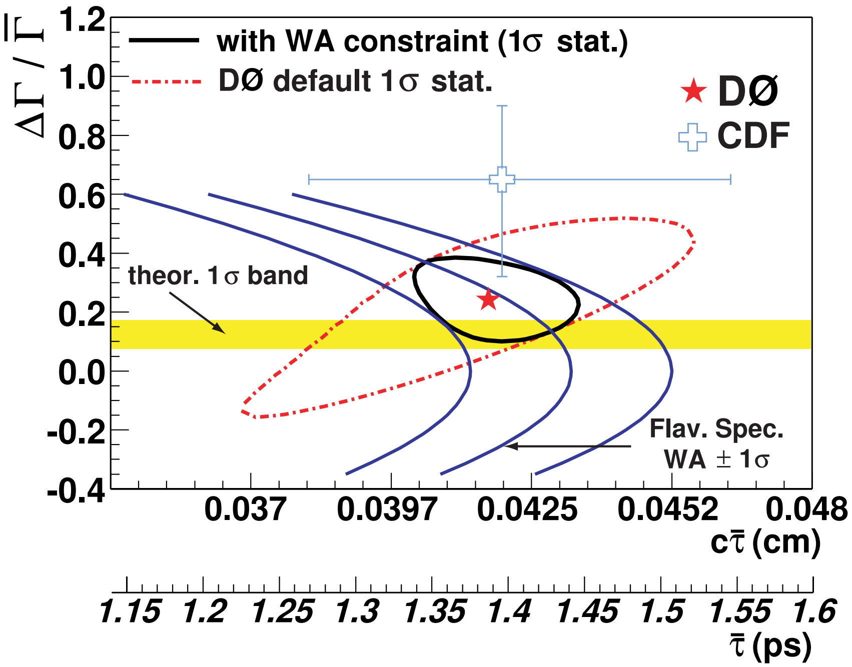
Semileptonic (flavor specific) measurements provide an independent relation of $\Delta\Gamma$ and Γ, leading to a significant improvement to $\Delta\Gamma$

A single-lifetime fit applied to flavor specific final state measures $\Gamma_{fs} = 1/\tau_{fs}$

$$\bar{\tau} = \bar{\tau}(f.s.)\frac{1+\left(\frac{\Delta\Gamma}{2\Gamma}\right)^2}{1-\left(\frac{\Delta\Gamma}{2\Gamma}\right)^2}$$

50% CP-even
50% CP-odd

Blue lines: World ave. flavor specific values (from semileptonic decays)



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$$\frac{\Delta\Gamma}{\bar{\Gamma}} = 0.24^{+0.28}_{-0.38}$$

$$\bar{\tau} = 1.39^{+0.13}_{-0.16}\ \mathrm{ps}$$

CDF

$$\frac{\Delta\Gamma}{\bar{\Gamma}} = 0.65^{+0.25}_{-0.33}$$

$$\bar{\tau} = 1.40^{+0.15}_{-0.13}\ \mathrm{ps}$$

With f.s constraint

$$\frac{\Delta\Gamma}{\bar{\Gamma}} = 0.25^{+0.14}_{-0.15}$$

$$\bar{\tau} = 1.39 \pm 0.06\ \mathrm{ps}$$

Mixing Summary

Preliminary limit on B_s mixing based on 610 pb^{-1} :

$B_S \rightarrow D_S\, \mu\, X$; $D_s \rightarrow \varphi\, \pi$; $\varphi \rightarrow K^+K^-$

$B_S \rightarrow D_S\, \mu\, X$; $D_s \rightarrow K^{*0}K$; $K^{*0} \rightarrow K\pi$

Limit: $\Delta m_s > 7.3\ ps^{-1}$ @ 95% confidence

Sensitivity: 9.5 ps^{-1} @ 95% confidence

Already competitive (second best sensitivity after ALEPH)

Excellent prospects in future with analysis/hardware improvements and more data

Can potentially cover entire SM range:
If no oscillations are observed : New Physics at some C.L. !

Lifetime Difference Summary **450 pb^{-1}**

Fit Values

$$\frac{\Delta\Gamma}{\overline{\Gamma}} = 0.24^{+0.28}_{-0.38}(stat)^{+0.03}_{-0.04}(syst)$$

$$R_{\perp} = 0.16 \pm 0.10(stat) \pm 0.02(syst)$$

$$\tau_L = 1.24^{+0.12}_{-0.11}(stat)^{+0.009}_{-0.012}(syst)\ ps$$

$$\tau_H = 1.58^{+0.44}_{-0.43}(stat)^{+0.012}_{-0.017}(syst)\ ps$$

$$\overline{\tau} = 1.39^{+0.13}_{-0.16}(stat)^{+0.01}_{-0.02}(syst)\ ps$$

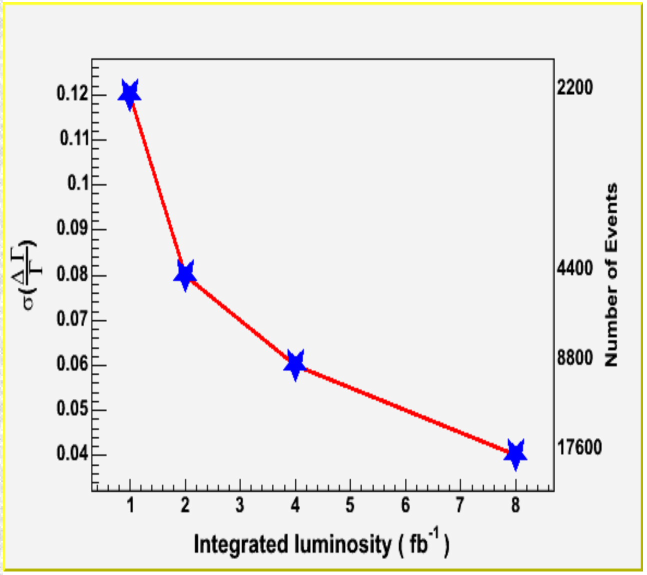
Flavor Specific Decay Constraint

$$\frac{\Delta\Gamma}{\overline{\Gamma}} = 0.25^{+0.14}_{-0.15} \qquad \overline{\tau} = 1.39 \pm 0.06\ ps$$

Ratio to B$_d$

$$\overline{\tau}_{Bd} = 1.530 \pm 0.043(stat) \pm 0.023(syst)\ ps \qquad \frac{\overline{\tau}_{Bs}}{\overline{\tau}_{Bd}} = 0.91 \pm 0.09(stat) \pm 0.003(syst)\ ps$$

Good agreement with theory



Future precision will improve with
- **More data**
- **Three angle analysis**
- **Using a tagged sample….**

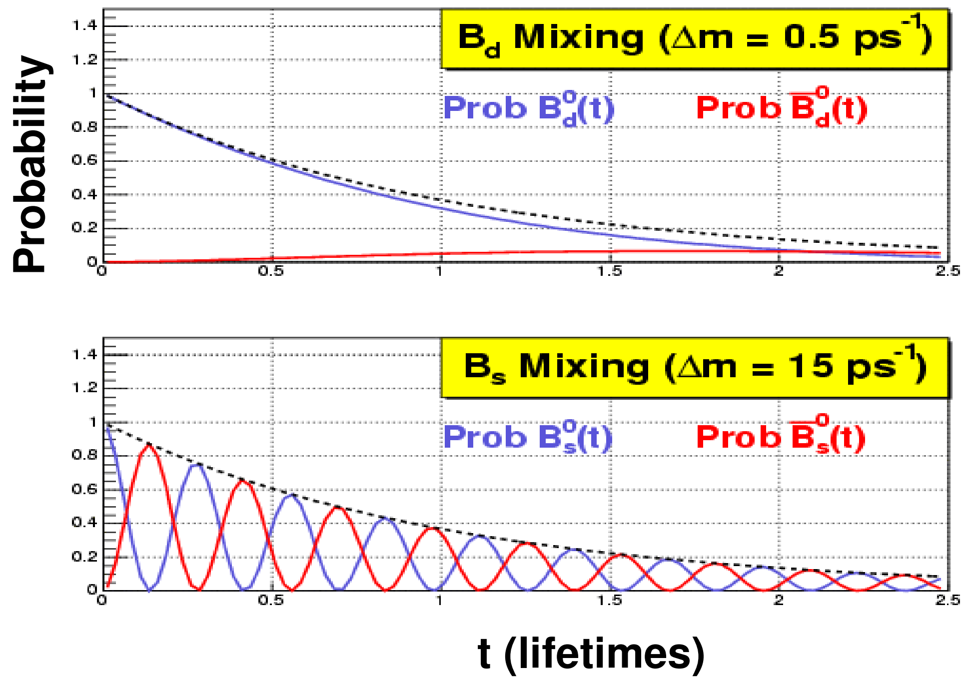
Might be able to exclude models predicting large CP violating phase

OR

Observe CP violation different from SM predictions

BACKUP SLIDES
(Mixing)

Sensitivity



Statistical Significance :

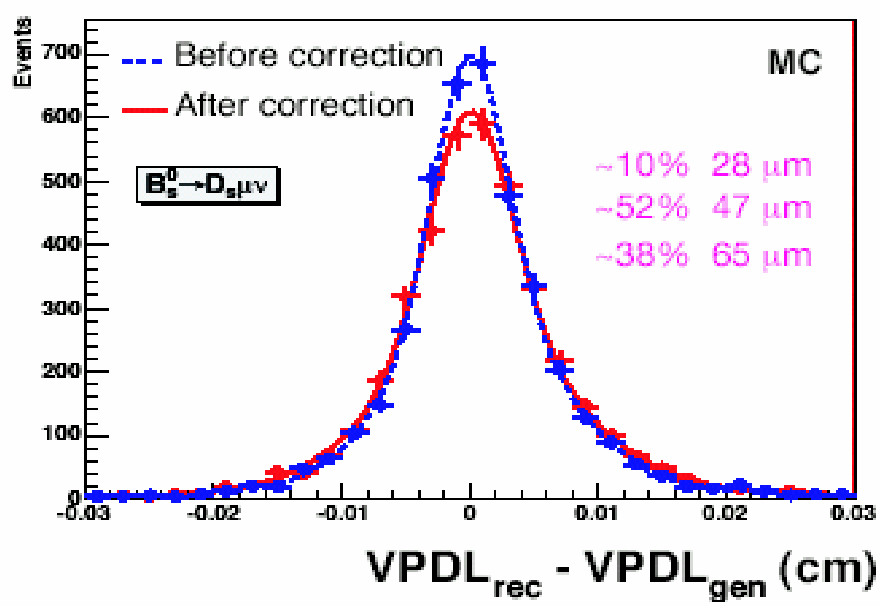
$$S(\Delta m, \sigma_t) = \sqrt{\frac{\varepsilon D^2 S}{2}} \sqrt{\frac{S}{S+B}} \times e^{-(\Delta m \sigma_t)^2/2}$$

Flavor tagging
D=2P-1
P: correct tag prob.

Signal purity

For large Δm, proper time resolution (σ_t) becomes v. imp.

VPDL resolution

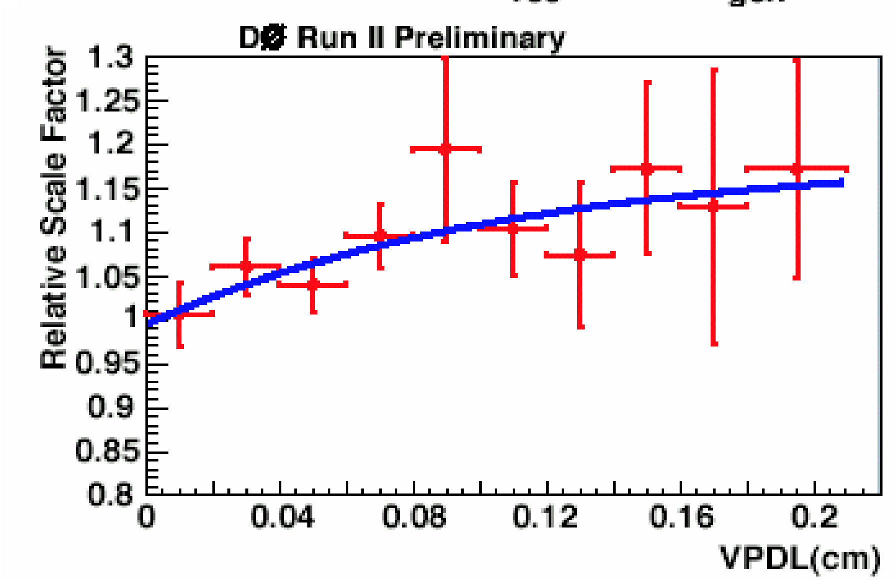


VPDL resolution from full detector simulation;

Describe VPDL resolution using 3 Gaussians

Adjusted by one global scale factor derived from data/simulation comparison.

1.142 ± 0.020	1.168 ± 0.024
$D_s \to \phi\,\pi$	$D_s \to K^{*0}K$

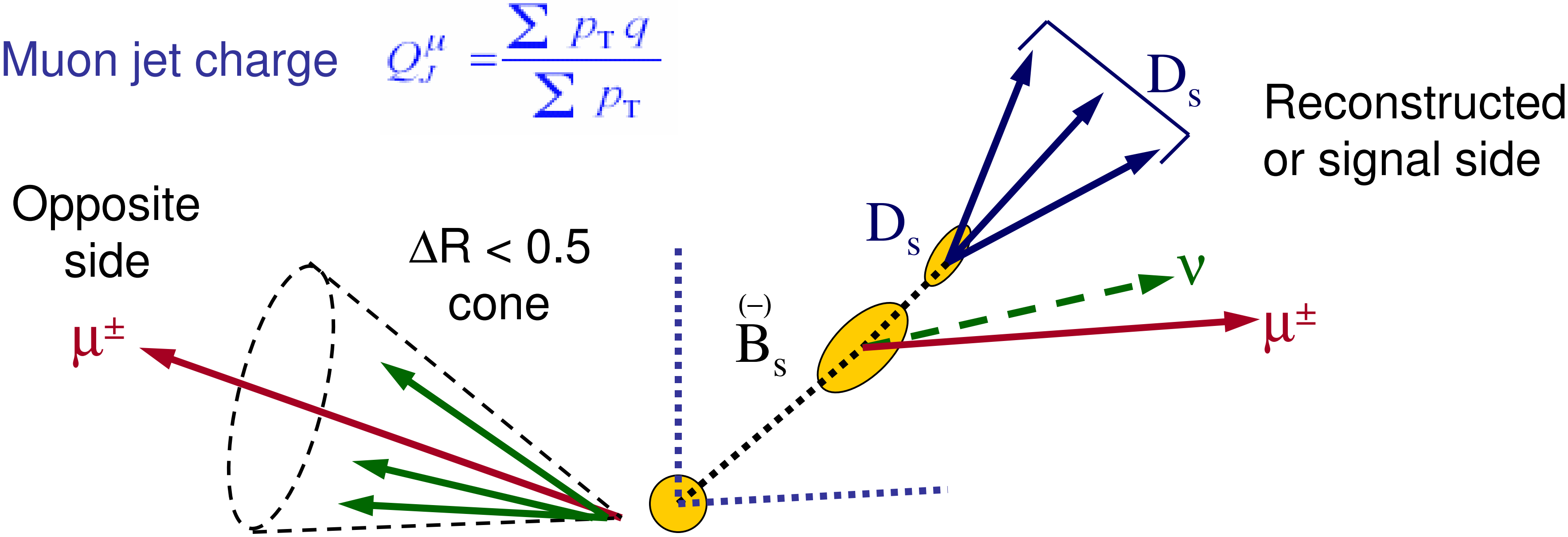


VPDL resolution depends on the VPDL (large VPDL correlated with large boost, *i.e.* with more collimated decay products).

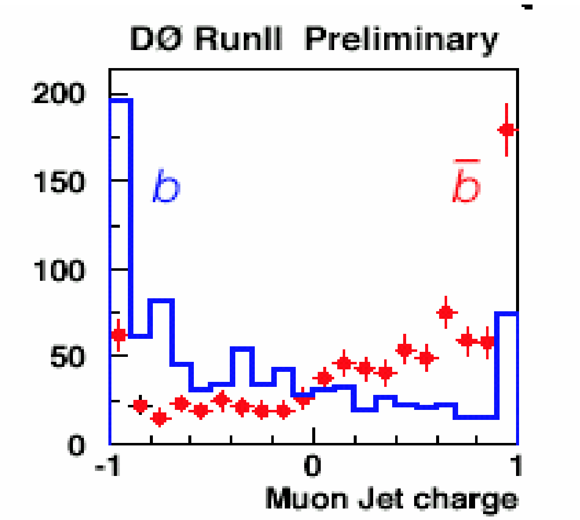
Use a VPDL dependent scale factor

Initial state flavor tagging

Muon jet charge $Q_J^{\mu} = \dfrac{\sum p_T q}{\sum p_T}$



If muon found with $\cos\phi(p_{\mu}, p_B) < 0.8$…



Combined Tagger

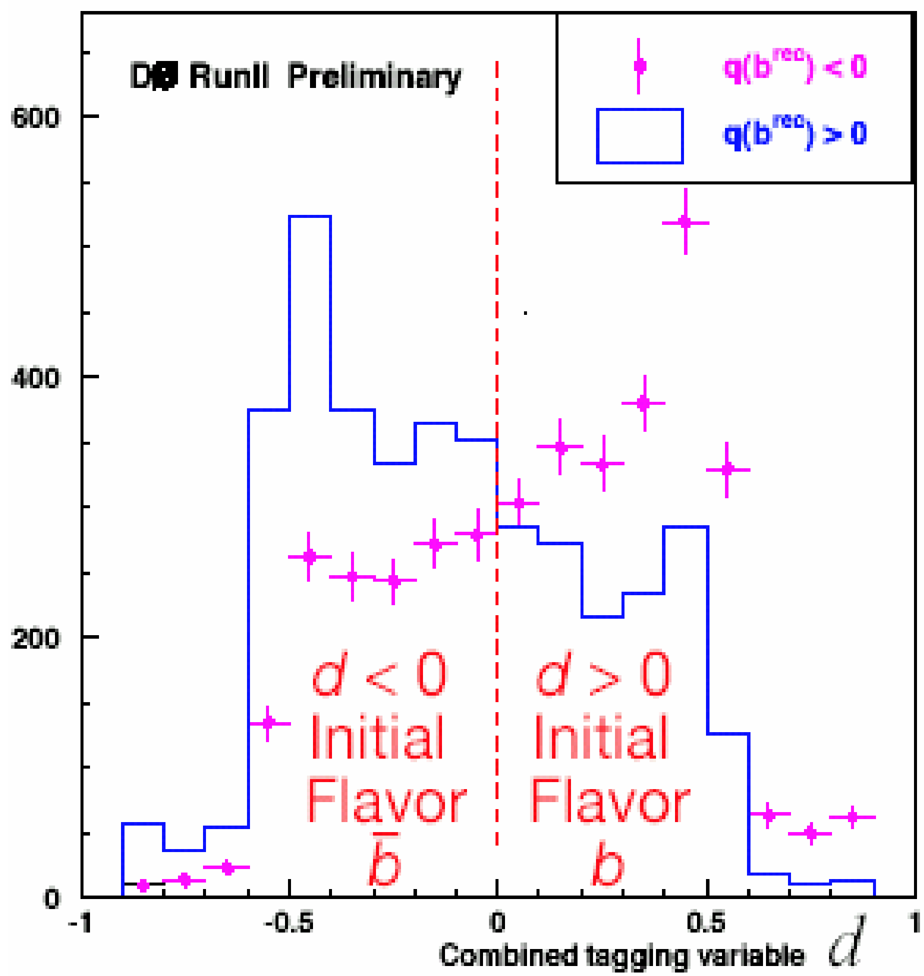
- For each discriminating variable x_i (described previously) construct P.D.F.s for the initial b [b] quark

- Combine different taggers using likelihood ratios:

$$Y = \prod_{i}^{n} y_i \;;\; y_i = \frac{f_i^{\bar{b}}(x_i)}{f_i^{b}(x_i)}$$

- Apply transformation to form single flavor-tag variable:

d=(1-y)/(1+y)



More pure ← → More pure

Tagger performance variables

$$\boxed{\text{Efficiency } \varepsilon = \frac{N_{correct} + N_{wrong}}{N_{correct} + N_{wrong} + N_{notag}}}$$

How often the tagging algorithm 'fires'

$$\boxed{\text{Dilution } D = \frac{N_{correct} - N_{wrong}}{N_{correct} + N_{wrong}}}$$

How often the tagging algorithm gives the correct answer

$$\boxed{D = 2\eta - 1}$$

η : purity of a tagger

$$\boxed{\text{Maximize tagging power: } \varepsilon D^2}$$

Dilution in data

- Make B_d oscillation measurement with same opposite-side tagger as for B_s
- Take |d| > 0.3:

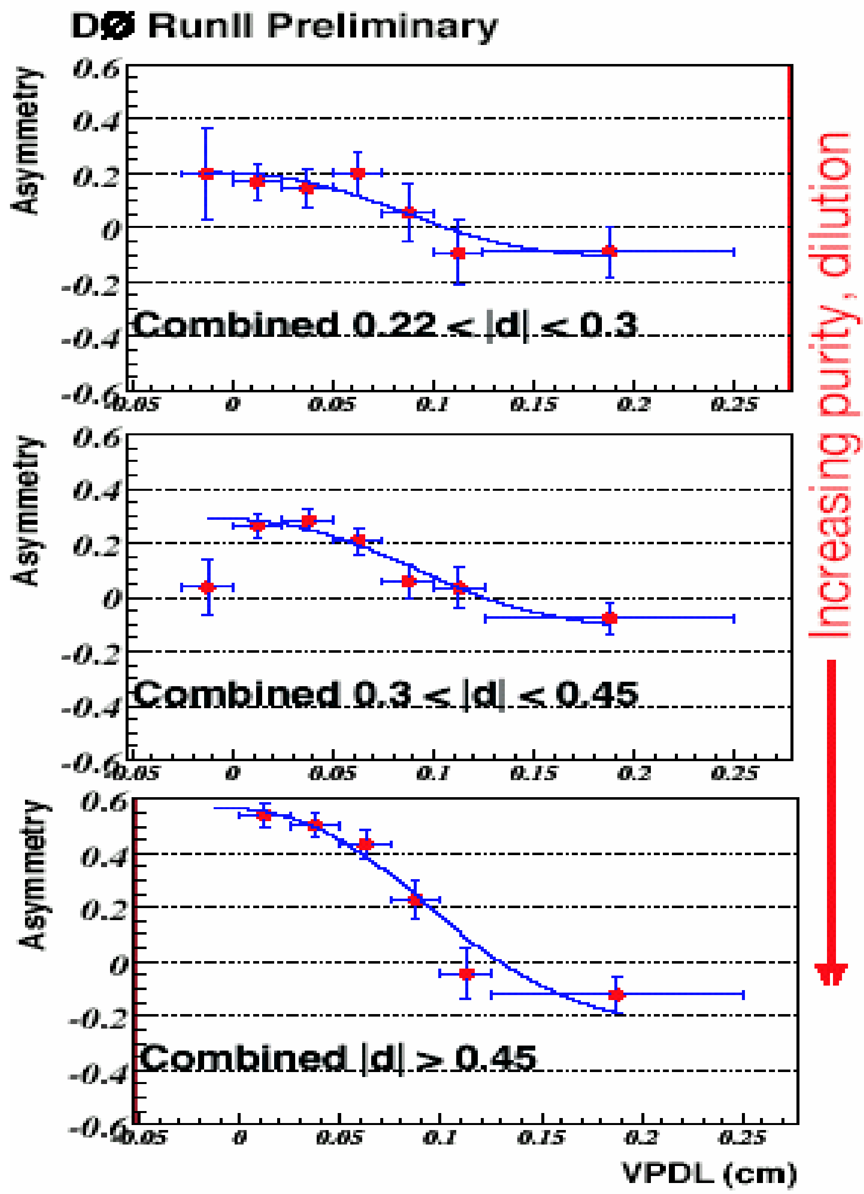
$$A_i = \frac{N_{osc} - N_{nosc}}{N_{osc} + N_{nosc}} = D \cos \Delta mt$$

  - Amplitude gives dilution
  - Frequency gives Δm_d

$\Delta m_d = 0.501 \pm 0.030 \pm 0.016\ ps^{-1}$
$D(B_d) = 0.414 \pm 0.023 \pm 0.017$
$D(B^+) = 0.368 \pm 0.016 \pm 0.008$

$D_{comb.}$ = 0.384 ± 0.014 ± 0.006
εD^2 = (1.94 ± 0.14 ± 0.09)%

- Use $D_{comb.}$ as input to B_s analysis (signal and opposite-side B species uncorrelated)



Sample Composition

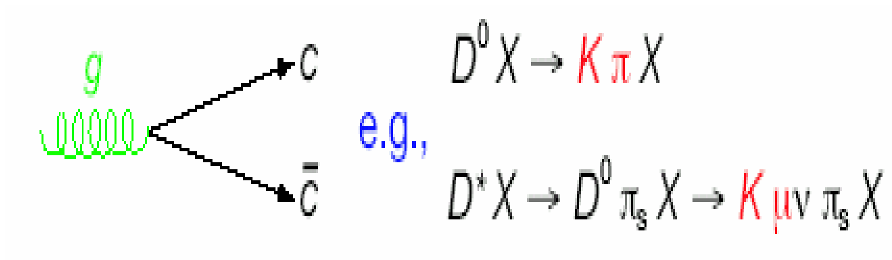
Composition of signal peak : estimate using MC simulation, PDG BRs…

$D_s \to K^{*0}K$

Decay	Sample fraction
$B_s \to D_s \mu\nu$	22.8%
$B_s \to D^*_s \mu\nu$	55.1%
$B_s \to D^*_{0s} \mu\nu$	1.2%
$B_s \to D^*_{1s} \mu\nu$	3.0%
$B_s \to D_s \tau\nu$	1.6%
$B_s \to D_s D_s X$	4.2%
$B_s \to D_s D X$	0.9%
$B^0 \to D_s D X$	5.6%
$B^- \to D_s D X$	5.7%

$c\bar{c}$ Contamination

Gluon splitting,
charm hadrons close to each other



Flavor tagging suppressed contribution by factor ~ 3

Estimated fraction of (3.5 ± 2.5)% from MC added in

Systematic errors

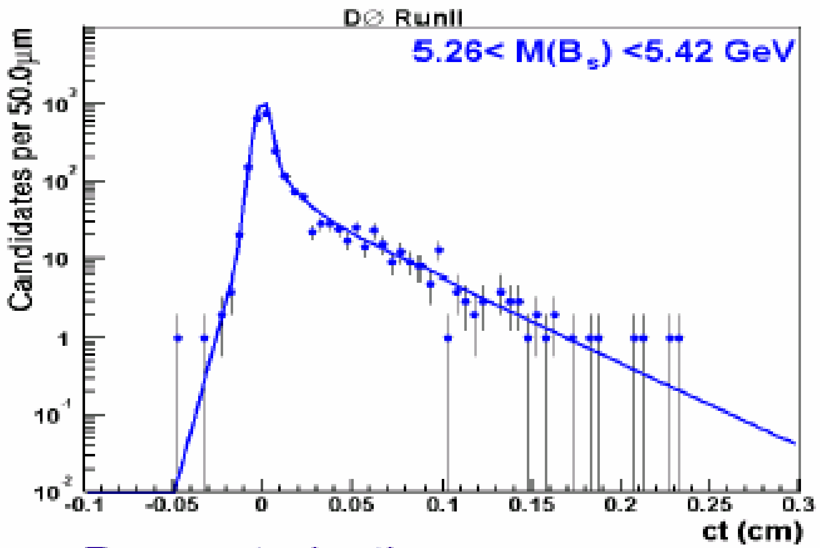
Done for each value of $\Delta \mathbf{m_s}$

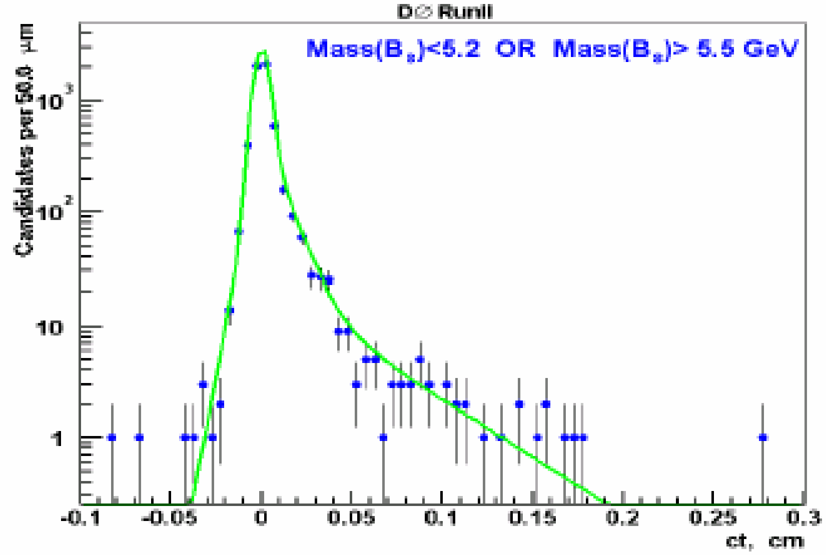
Example: $D_s \rightarrow K^{*0}K$

Dominant systematic (7 ps^{-1})	σ^{tot}
Mass fitting	0.13
Sample composition	0.10
K-factor uncertainty	0.09
VPDL res. scale factor uncertainty	0.07
Dilution uncertainty	0.04

BACKUP SLIDES

(Lifetime difference)





Parameterisations

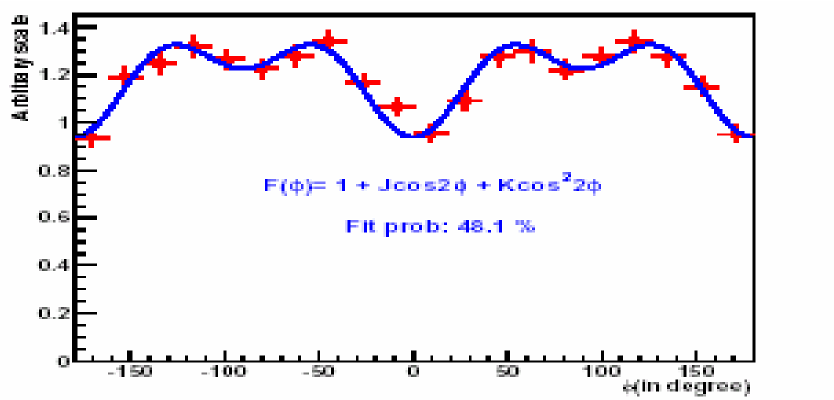
- Mass: double Gaussian with common mean (signal)
  two 1st order polynomials (prompt & non prompt)
- Lifetime: 2 exponential x gaussians (CP odd and even)
  1 gaussian (prompt) 3 exponentials (+ and – cτ non prompt)
- Transversity: $(1+\cos^2\theta)\ G(\theta)$ CP even $(1-\cos^2\theta)\ G(\theta)$ CP odd
  2 polynomials ($G(\theta) = 1+A\cos^2\theta+B\cos^4\theta$) for prompt & non prompt

19 Free Parameters

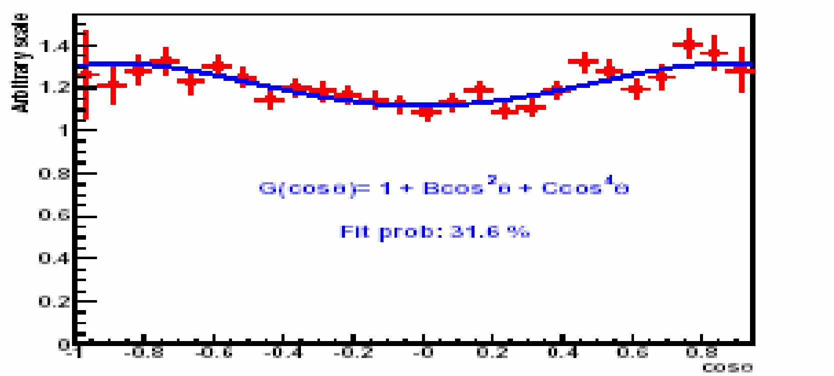
Untagged B_s rate in time/angles

$$
\begin{aligned}
\frac{d^3\Gamma\left(\to J/\psi\,(\to l^+l^-)\,\phi(\to K^+K^-)\right)}{d\cos\theta\; d\phi\; d\cos\psi\; dt} \propto \frac{9}{16\pi}\Big[\; & 2|A_0(0)|^2\, e^{-\Gamma_L t}\cos^2\psi\,(1-\sin^2\theta\,\cos^2\phi) \\
& + \sin^2\psi\left\{|A_{\parallel}(0)|^2\, e^{-\Gamma_L t}(1-\sin^2\theta\,\sin^2\phi) + |A_{\perp}(0)|^2\, e^{-\Gamma_H t}\sin^2\theta\right\} \\
& + \frac{1}{\sqrt{2}}\sin 2\psi\left\{|A_0(0)||A_{\perp}(0)|\cos(\delta_2-\delta_1)\,e^{-\Gamma_L t}\sin^2\theta\,\sin^2 2\phi\right\} \\
& + \left\{\frac{1}{\sqrt{2}}|A_0(0)||A_{\perp}(0)|\cos\delta_2\,\sin 2\psi\,\sin 2\theta\,\cos\phi\right\}\frac{1}{2}\left(e^{-\Gamma_H t}-e^{-\Gamma_L t}\right)\delta\phi \\
& - \left\{\frac{1}{\sqrt{2}}|A_{\parallel}(0)||A_{\perp}(0)|\cos\delta_1\,\sin^2\psi\,\sin 2\theta\,\sin\phi\right\}\frac{1}{2}\left(e^{-\Gamma_H t}-e^{-\Gamma_L t}\right)\delta\phi\;\Big]\; H(\cos\psi)\,F(\phi)\,G(\cos\theta)
\end{aligned}
$$

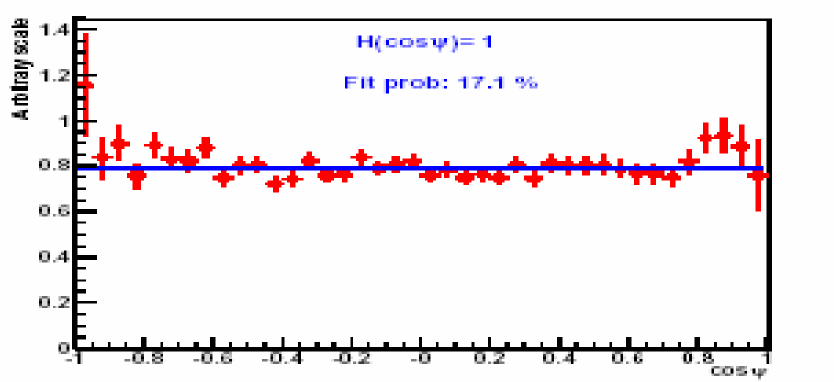
Detector Acceptance (MC)



$F(\phi) = 1 + J\cos(2\phi) + K\cos^2(2\phi)$



$G(\cos\theta) = 1 + B\cos^2\theta + C\cos^4\theta$



$H(\cos\psi)$ flat distribution

3 angles → 1 angle

Inserting $H(\cos\psi) = 1$, and $F(\phi) = 1 + J\cos(2\phi) + K\cos^2(2\phi)$, and

integrating over $\cos\psi$ and ϕ, we obtain a 1-angle time evolution:

$$\frac{d^3\Gamma \to J/\psi\,(\to l^+l^-)\,\phi(\to K^+K^-)}{d\cos\theta\; dt} = N\pi \Big[\left(|A_0(0)|^2 + |A_{\parallel}(0)|^2\right) e^{-\Gamma_L t} (1+\cos^2\theta)$$

$$+ \frac{K}{2}\left\{ \left(|A_0(0)|^2 + |A_{\parallel}(0)|^2\right) e^{-\Gamma_L t}(1+\cos^2\theta) \quad + 2\,|A_{\perp}(0)|^2 e^{-\Gamma_H t}\sin^2\theta \right\}$$

$$- \frac{J}{2}\left(|A_0(0)|^2 - |A_{\parallel}(0)|^2\right) e^{-\Gamma_L t}\sin^2\theta \quad + 2\,|A_{\perp}(0)|^2 e^{-\Gamma_H t}\sin^2\theta \Big]\; G(\cos\theta)$$

0.355 ± 0.066 (from CDF)

$$|A_0(0)|^2 + |A_{\parallel}(0)|^2 + |A_{\perp}(0)|^2 = 1$$

defining, $R_{\perp} = |A_{\perp}(0)|^2$

In pursuit of new physics

(1) We measure correlated parameters

$\Delta\Gamma/\Gamma = (\Delta\Gamma/\Gamma)_{SM} \cos^2(\delta\phi)$ and τ

(2) Semileptonic measurements relate

$(\Delta\Gamma/\Gamma)_{SM}\cos(\delta\phi)$ and τ.

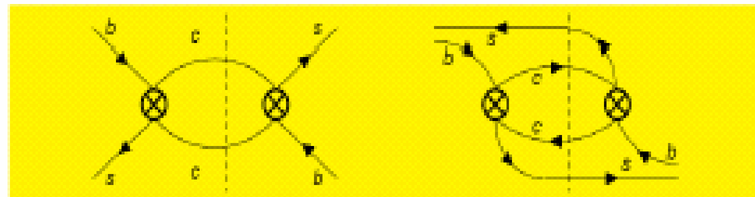
Fit to (1--3) for $\cos(\delta\phi)$:

$$|\cos(\delta\phi)| = 1.46^{+0.73}_{-0.69}$$

(3) SM predicts (A. Lenz,hepph/0412007)

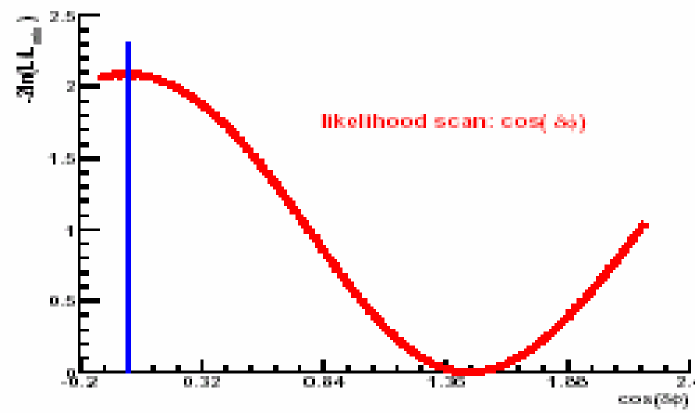
$(\Delta\Gamma/\Gamma)_{SM} = 0.12 \pm 0.05$

Γ_{12} stems from final states common to B_s and $\overline{B}_s$.



Crosses: Effective $|\Delta B| = 1$ operators from W-exchange.

Γ_{12} is a CKM-favored tree-level effect associated with final states containing a $(\bar{c}, c)$ pair.



Angular momentum

Angular Momentum

- $0^- \rightarrow 1^-{}_L 1^-$ L ≡ relative orbital angular momentum
    - So L=0,2 are CP even and L=1 is CP odd

We integrate over 2 angles
(transversity is good angle for CP odd/even separation)

Non-uniform acceptance in ϕ integration leads to small correction term

Very Small

Use CDF result = 0.355 ± 0.066

$$\frac{d^2\Gamma}{d\cos\theta\, dt} \propto \left[N_1\left(|A_0(0)|^2 - |A_\parallel(0)|^2\right)e^{-\Gamma_L t}\left(1+\cos^2\theta\right) + 2N_2|A_\perp(0)|^2 e^{-\Gamma_H t}\sin^2\theta\right]$$

$R_\perp \equiv$ CP odd fraction at t = 0

CP Even

CP Odd

Systematic errors

Source	$c\tau(B_s^0)$, μm	$\Delta\Gamma/\overline{\Gamma}$	$R_\perp$
Acceptance vs. $\cos\theta$	± 0.6	± 0.001	± 0.005
Integration over φ, ψ	± 0.2	± 0.001	± 0.02
Procedure test	± 2.0	± 0.025	± 0.01
Momentum scale	-3.0	–	–
Signal mass model	± 1.0	$+0.009, -0.017$	± 0.007
Background mass	-3.5	$+0.02$	-0.002
Detector alignment	± 2.0	–	–
Background model	± 0.5	± 0.016	± 0.005
Total	$-5.6, +3.1$	$-0.04, +0.03$	± 0.02

Selection cuts

p_T of $\mu^+ \mu^-$	>1.5 GeV (> 4.0 GeV if $\|\eta\|$ < 1.0)
χ^2 of J/ψ vertex	< 10.0
J/ψ candidate mass	2.90 < $M(\mu^+,\mu^-)$ < 3.25 GeV
J/ψ decay length error	< 0.03 cm
p_T of $K^+ K^-$	>0.7 GeV
χ^2 of ϕ vertex	< 15.0
ϕ candidate mass	1.01 < $M(K^+,K^-)$ < 1.03 GeV
p_T of ϕ	> 1.5 GeV
SMT hits on track	> 0
CFT hits on track	> 0
SMT+CFT hits on track	> 3
p_T of B_s	> 6.0 GeV
B candidate decay length error	< 0.006 cm
Absolute decay length difference between B_s candidate and J/ψ	< 0.04 cm
B_s candidate mass	5.0 < $M(J/\psi,\phi)$ < 5.8 GeV